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CHAPTER 7.4

SOLDERED AND BRAZED ASSEMBLIES*

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THE PROCESS

Soldering and brazing are closely related processes in which metal components are joined together by means of a filler metal. The filler metal, which has a melting point lower than that of the base metal, is introduced to the heated joint. It melts, wets the surface to be joined, and is distributed in the joint by capillary attraction.

In the case of soldering, the filler metal, called *solder*, has a melting point (liquidus) below 425°C (800°F). Common solders consist chiefly of tin and lead. In the case of brazing, the filler metal has a melting point (liquidus) above 425°C (800°F). The most common brazing metals are alloys of either silver or copper.

Heat can be applied to the joint in a number of ways. The more significant heat sources in use in industry are (1) heated iron (solder only), (2) gas torch, (3) furnace, (4) induction coils, (5) dipping in (a) molten filler metal or (b) a molten salt bath, (6) electrical resistance (of the workpiece itself), and (7) infrared lamps.

Wetting action is crucial to successful soldering and brazing. It requires that the joint surfaces be chemically clean. A first step in these processes is invariably a cleaning operation. Cleanliness is maintained during heating by means of flux or a protective atmosphere.

TYPICAL CHARACTERISTICS

Brazed and soldered assemblies represent configurations that are impractical or uneconomical to make from a single piece. This may occur when:

*This chapter deals primarily with mechanical applications. Electronics assemblies are covered in Chap. 9.4.

1. Dissimilar metals are involved, e.g., a carbide tool bit and a steel-alloy shank.
2. Light weight is important, but the shape is intricate, e.g., for an assembly of bent tubing and fittings.
3. The part is too intricate to machine from one piece, especially because of thin sections, and when high strength and accuracy are important.
4. Hollow shapes such as tanks, floats, and evaporators are involved. (Leaktight joints often dictate the use of soldering or brazing.)

Brazed and soldered assemblies most often are composed of one or more sheet-metal components. Additional components may be machined parts, forgings, and in some cases, castings.

Most brazed assemblies are not large because heating, cleaning, and handling costs are compounded with larger size. Resistance-heated joints are normally less than 1 in² in area. Furnace-brazed assemblies are seldom larger than 2.5 kg (5.5 lb). Figures 7.4.1 and 7.4.2 show typical production-brazed assemblies.

Soldered assemblies are used when strength requirements are not as great, when a capability of later disassembly is important, or when electrical conductivity or fluid sealing is the prime requirement. Brazing is employed rather than soldering when strength requirements are greater. Strength capabilities of brazed joints are significant. Tensile strengths of 830 MPa (120,000 lbf/in²) are feasible with silver brazing alloys,



FIGURE 7.4.1 Typical brazed assemblies. (Courtesy Handy & Harmon.)

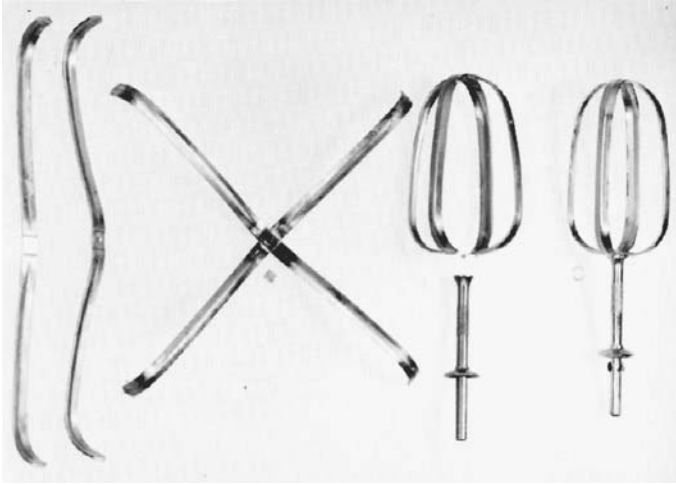


FIGURE 7.4.2 This light and strong brazed beater assembly would be difficult to fasten with other methods. (Courtesy Handy & Harmon.)

for example. Brazing may be used when postjoining heat treating is required. Brazed assemblies also can offer good corrosion resistance and a neat appearance.

ECONOMIC PRODUCTION QUANTITIES

Brazing and soldering are suitable for a broad range of production quantities. Hand-torch brazing requires a certain amount of operator skill but very little investment for equipment or tooling. It is therefore a suitable technique for the maintenance shop and few-of-a-kind production.

Other heating methods require some investment for equipment and tooling and therefore require some production quantity for amortization. In general, however, these investments are moderate, and brazing and soldering have proved to be good processes at medium as well as higher production levels, with a variety of heat-application methods. The exception is conveyorized-furnace brazing, which requires substantial production volume to be justifiable because of the cost of furnaces, atmosphere generators, and sometimes fixtures.

Table 7.4.1 summarizes, in general terms, the investment cost and production-level applicability of various heating methods.

SUITABLE MATERIALS

Soldering

Solders are available in bar, wire (solid or flux-cored), and paste forms. The bar forms

TABLE 7.4.1 Economic Production Quantities and Relative Investment Costs for Various Soldering and Brazing Methods*

Heating method	Relative investment required		Economic production quantities	Remarks
	Equipment	Tooling		
Hand torch	VL	L [†]	VL–L	
Automatic torch	M–H	M–H	M–H	Fixtures required
Induction	M	M	M	Special coil and fixture required for each assembly
Metal dipping	L–M	M	L–M	Fixture required
Resistance	M–H	M	M–H	
Furnace	H	H [‡]	M–VH	
Infrared	M	M	M–H	

*VL = very low; L = low; M = medium; H = high; VH = very high.

†If a fixture is required; otherwise, very low.

may be used in tinning pots or wave soldering machines for electronic circuit boards. Wire forms are used for hand or automatic soldering for assembly and repair. Pastes are comprised of solder particles blended in a rosin-based or organic acid flux vehicle.

Recent concerns about leaching of the lead component of solders in copper water supply systems and scrapped electronic and other products have fostered legislative efforts to encourage the use of lead-free solders. Several commercially available lead-free solders are listed in Table 7.4.2, which lists commercially available solders, their compositions, melting temperatures, and common applications.

Base metals vary in their ability to accept solder. The following metals are solderable and are listed in order of decreasing solderability:

- | | |
|------------|---------------------|
| 1. Tin | 10. Zinc |
| 2. Cadmium | 11. Steel |
| 3. Silver | 12. Inconel |
| 4. Copper | 13. Stainless steel |
| 5. Brass | 14. Chromium |
| 6. Bronze | 15. Nichrome |
| 7. Lead | 16. Silicon bronze |
| 8. Nickel | 17. Alnico |
| 9. Monel | 18. Aluminum |

Metals numbered from 1 to 10 can be soldered with noncorrosive flux. Difficult-to-solder base metals can be electroplated or dip-coated with tin, copper, silver, lead-tin, nickel, zinc, or cadmium to provide a base for solder.

Brazing

TABLE 7.4.2 Common Commercial Solder Alloys

ASTM classification	Major composition, %	Melting range, °F	Tensile strength, lbf/in ²	Typical applications
Sb	5 Sb–94 Pb (min)	450–464		For coating and joining metals subject to high operating temperatures
Sn 5A	5 Sn–95 Pb	586–594	4,190	General purpose (higher temperature)
Sn 20A	20 Sn–80 Pb	361–535	5,140	Automobile body repair
Sn 20B	20 Sn–1 Sb–79 Pb	363–517	5,300	Auto body repair, stronger, but avoid galvanized
Sn 30A	30 Sn–70 Pb	361–491	6,140	Auto body repair, dip solder wire stripping
Sn 30B	30 Sn–1.6 Sb–68.4 Pb	364–482	6,460	Auto body repair
Sn 40A	40 Sn–60 Pb	361–455	6,320	Cable sheaths, dip soldering
Sn 40B	40 Sn–2 Sb–58 Pb	365–448	7,100	General purpose, not for galvanized
Sn 50	50 Sn–50 Pb	361–421	6,450	General purpose, plumbing, noncritical electrical
Sn 60	60 Sn–40 Pb	361–374	6,400	Electrical and electronic
Sn 62	62 Sn–36 Pb–2 Ag	354–372		Electronics, for silver-coated surfaces
Sn 63	63 Sn–37 Pb	361–361		Electronics, printed circuit boards
Ag 5.5	94.5 Pb–1.5 Ag	579–689	4,000	For copper, brass at higher temperature (to 350°F)
Ag 1.5	97.5 Pb–1.5 Ag–1 Sn	588–588	3,600	
Lead-free alloys:				
Sn 95	95 Sn–5 Ag	430–473	10,100	Medical, potable water, jewelry
	95 Sn–5 Sb	455–464	5,900	Plumbing joints
Sn 96	96.5 Sn–3.5 Ag	430–430	14,000	Food, nontoxic applications, higher joint strength
	80 Sn–20 Zn	390–518		For soldering aluminum
	40 Cd–60 Zn	509–635		For soldering aluminum
	50 Sn–50 In	243–260	1,200	For soldering glass to metal or itself

The brazing process is applicable to a wide variety of base metals. Many common materials used in production—carbon and alloy steel, copper, brass, aluminum, cast iron, nickel, and nickel alloys—all can be brazed successfully. Some base metals require special processing steps. The following is a discussion of the brazability of common base metals.

Low-Carbon Steel. This metal is very suitable for brazing. When quantities are sufficient to justify furnace brazing, copper brazing alloy is the recommended filler metal because of its low cost.

High-Carbon and Alloy Steels. These steels are fully brazable. Special steps or added operations may be necessary, however, to preserve the metallurgical condition of the steel. Grain coarsening can occur as a result of copper furnace brazing of such steels. Cooling after brazing can cause hardening, and subsequent annealing may be required. Fortunately, copper-brazed assemblies can be subjected to the temperatures required to anneal the base metal without difficulty. Other heat-treating operations also can be performed on copper-brazed assemblies.

Stainless Steel. This metal is frequently brazed. Generally, the weldable grades of stainless steel are also the most brazable. Stainless steel tends to be more difficult to clean fully of surface oxides before brazing and therefore may produce incompletely filled joints. It is more difficult to braze than low-alloy or carbon steels.

Cast Iron. Cast iron is difficult to braze because of its graphite content, which necessitates special cleaning procedures. The brazing heat also can adversely affect the strength and hardness of the iron. Malleable iron is the most brazable cast iron, ductile iron is next, and conventional gray iron is least brazable, especially the high-silicon grades.

Copper and Copper Alloys. These metals, including brass, are relatively easily brazed. Possible exceptions are leaded brasses and silicon bronze.

Aluminum. Aluminum is difficult to braze because of the closeness of the melting temperature of the base and filler metals and because of the rapidity of formation and adherence of aluminum oxide. The following classes of alloys are more easily brazed: 1XXX, 3XXX, and 6XXX. The 2XXX and 7XXX grades are more difficult.

Titanium. Titanium requires special brazing alloys and processing steps.

Table 7.4.3 lists typical brazing alloys, their melting temperatures, and their recommended applications.

DETAILED DESIGN RECOMMENDATIONS

Joint Design

The design of a joint, of course, depends on a number of factors such as strength and service requirements, whether pressure-tightness and electrical conductivity are involved, composition of the metals to be joined, and the brazing alloy. There are

TABLE 7.4.3 Common Commercial Brazing Alloys

Classification	Composition, %	UNS designation	Melting range, °F	Optimal gap, in	Typical applications
B Ag-1 (AWS)	45 Ag-15 Cu-15.5 Zn-24 Cd	P07450	1125–1145	0.0015–0.002	General purpose; OK for cast iron
B Ag-1a (AWS)	50 Ag-15.5 Cu-16.5 Zn-18 Cd	P07500	1160–1175	0.0015–0.002	General purpose; higher strength
B Ag-2 (AWS)	35 Ag-26 Cu-21 Zn-18 Cd	P07350	1125–1295	0.003–0.006	For building up, bridging, and filletting
B Ag-3 (AWS)	50 Ag-15 Cu-15.5 Zn-16 Cd-3 Ni	P07501	1170–1270	0.003–0.006	For building up, bridging, and filletting; for carbide tool bits
B Ag-4 (AWS)	40 Ag-30 Cu-28 Zn-2 Ni	P07400	1240–1435	0.003–0.006	For tungsten, stellite, refractory alloys
B Cu-1 (AWS)	99 + Cu	C14180	1980–1980	0.000	For furnace-brazing ferrous metals
B Cu Zn-1 (AWS)	60 Cu-40 Zn	C28000	1650–1660	0.002–0.006	General-purpose torch and induction
B Cu P-2 (AWS)	93 Cu-7 P	C55181	1305–1485	0.001–0.003	For copper, brass, and bronze; not steels
B Cu P-5 (AWS)	15 Ag-85 Cu-5 P	C55284	1185–1500	0.003–0.005	
B Al Si-3 (AWS)	86 Al-10 Si-4 Cu	A94145	970–1085	0.006–0.025	General purpose for dip and furnace brazing of aluminum
B Al Si-4 (AWS)	88 Al-12 Si	A94147	1070–1080	0.002–0.010	
B Mg-1 (AWS)	89 Mg-9 Al-2 Zn	M19001	770–1110	0.004–0.010	General purpose for magnesium
B Ni-1 (AWS)	Ni-14 Cr-4 Si-3.5 B-4.5 Fe-0.75 C		1790–1900	0.001–0.003	For stainless and heat-resistant alloys
B Ni-2 (AWS)	Ni-7 Cr-4.5 Si-3.1 B-3.0 Fe		1780–1830	0.001–0.003	For stainless and heat-resistant alloys
B Ni-3 (AWS)	Ni-4.5 Si-3.1 B-0.5 Fe		1800–1900	0.001–0.003	For stainless and heat-resistant alloys

some constant principles that can be applied, however. For example, the prime requirement is to provide opportunity for filler metal to flow into the joint by capillary attraction. This requires a close gap between surfaces of the joint. The strength of the joint lies more in the film of filler metal between the parts than it does in fillets at the edges of the joint.

Lap joints should be used whenever possible because they provide an easy means for controlling the joint area and gap and usually do not present assembly or fixturing problems. The joint area (overlap) should be sufficiently large so that the joint is as strong as the weaker member of the assembly.

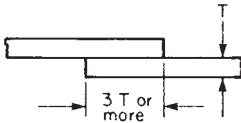


FIGURE 7.4.3 Lap joint (recommended).



FIGURE 7.4.4 Butt joint (not recommended).

Allowance must be made for the usual lower unit strength of the filler metal compared with the base metal and the possibility of voids within the joint. One rule of thumb is to allow an overlap of at least three times the thickness of the thinnest member. (See Fig. 7.4.3.)

The clearance between joint surfaces can be critical. Its amount depends on the fluidity of the filler metal. Normally from 0.025 to 0.20 mm (0.001 to 0.008 in) is specified, with an average value of perhaps 0.10 mm (0.004 in).

Butt joints (see Fig. 7.4.4) are not recommended unless strength requirements are very low and there is no need for a pressure seal at the joint. The joint area in a butt joint is small, and there is a greater possibility of variations from squareness and flatness within the joint. These variations interfere with the filling action of the solder or braze material. Butt joints may be satisfactory for electrical applications, but they do add to the resistance of the circuit.



FIGURE 7.4.5 Scarf joint (not recommended).

but they do add to the resistance of the circuit.

Scarf joints (Fig. 7.4.5) are occasionally used in place of butt joints because they can be produced with a greater joint area. If the joint area is three or more times the stock thickness, they are satisfactory from a strength standpoint. From a manufacturability standpoint, however, they are not recommended because of the cost of the machining necessary for the diagonal surfaces and the difficulty in holding the parts in the proper assembled position during the brazing or soldering operation.

Figure 7.4.6 shows a number of both recommended and not-recommended joint configurations.

Assembly

Parts that comprise brazed assemblies should be designed so that they are easily assembled to one another. Chapter 7.1 covers this subject and gives design suggestions to facilitate assembly.

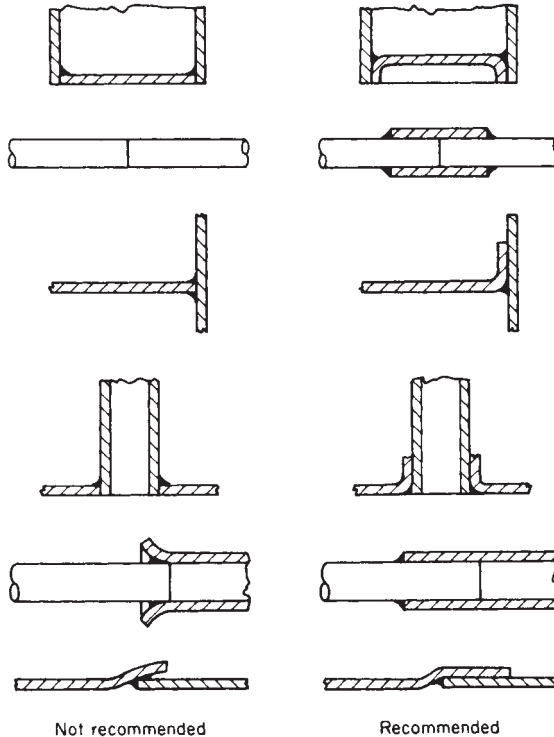


FIGURE 7.4.6 Joint configurations for soldering and brazing.

The most economical soldered and brazed assemblies are those which are self-jigging, i.e., those in which the assembled parts and the filler metal hold together during the heating cycle without any external fixture. This principle applies regardless of the heating method for the following reasons:

1. Self-jigging avoids the cost of building and maintaining fixtures.
2. It minimizes the possible problem of having the parts braze to the fixture as well as to each other. Some brazing alloys (e.g., copper) flow extensively and may not confine themselves to the joint area.
3. Self-jigging eliminates the cost of loading and unloading parts from fixtures.
4. Self-jigging reduces the heating load and therefore the heating cost.
5. It gives better dimensional control than is usually obtained with fixtures, which must allow for both part-to-part dimensional variations and thermal expansion. It is often possible, when self-jigging is used, to accommodate such variations with no loss of accuracy.

There are a number of self-jigging methods. They involve the following approaches for holding parts together: gravity, spot and tack welding, friction and press fits, staking and peening, swaging, crimping and forming, threading, and riveting. See Fig. 7.4.7 for illustrations of these methods.

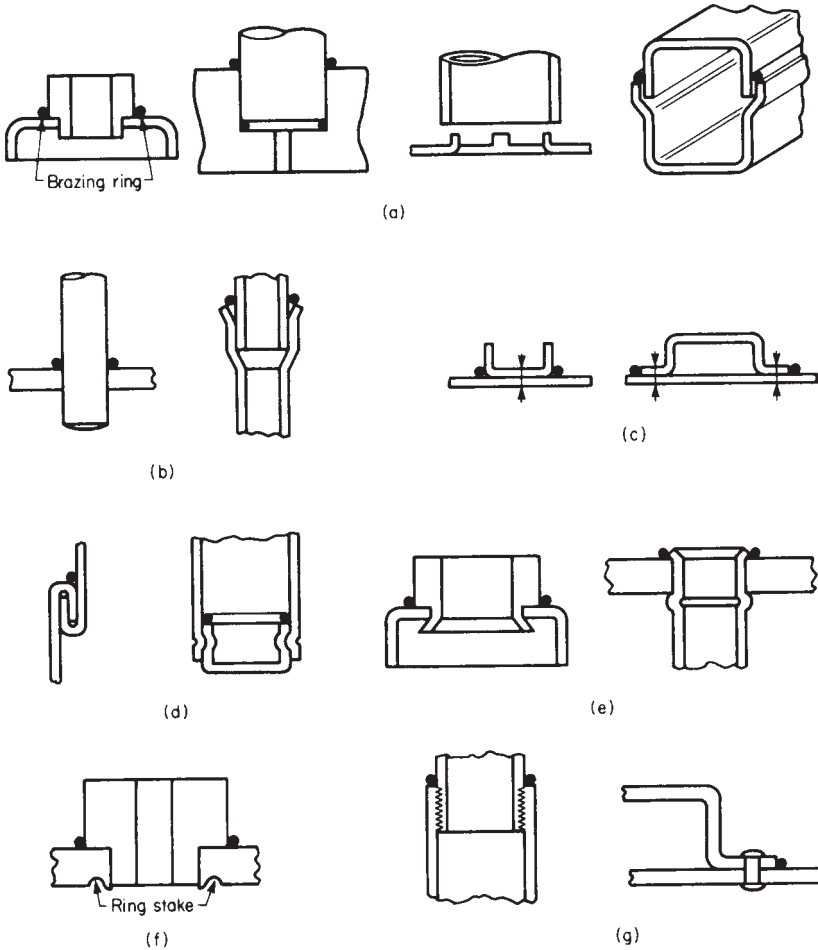


FIGURE 7.4.7 Various self-jigging methods for brazed assemblies. (a) Gravity is the most convenient force to use for self-jigging parts to be brazed. (b) Press-fit joint is used when the parts are not self-locating in all planes. (c) Spot and tack welding may be used when part configurations preclude the use of press fits. (d) Crimping or forming. (e) Expanding and swaging. (f) Staking and peening. (g) Threading and riveting form excellent self-locking and self-jigging joints for brazing and soldering operations. (Illustrations reprinted from *Assembly Engineering*, by permission of the publisher, © 1972, Hitchcock Publishing Company. All rights reserved.)

Placement of Braze Metal

Solder and braze metal can be in a number of forms that permit preplacement before heating. These are wire (commonly formed into rings for circular joints), slugs, shims, paste, and sprayed or plated coatings. The last named are especially applicable to copper brazing.

Because of copper's strong capillary action, it can be placed some distance from

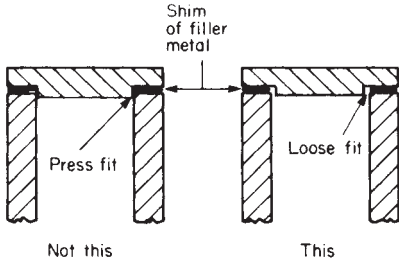


FIGURE 7.4.8 When filler metal in shim form is used, allow looseness between parts so that they can settle together when the filler metal flows, providing a stronger joint.

the joint and still produce satisfactory results. Nevertheless, for copper and especially for more viscous filler metals, the joint should be designed so that the filler metal stays put during the operation.

When filler metal is used in shim form, the assembly should be such that the parts are free to move when the filler metal melts. This allows a stronger, narrow-gap joint. (See Fig. 7.4.8.)

Joints should be designed to avoid gas entrapment. The best way to ensure this is to provide a vent hole in the joint.

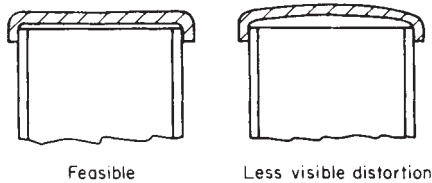


FIGURE 7.4.9 Use curved areas if possible.

Other Considerations

The high temperature of brazing can cause distortion of the parts. Large, unsupported flat areas should be replaced by curved areas if possible, because the latter are more self-supporting. (See Fig. 7.4.9.)

When brazing tanks or other enclosed assemblies, a vent must be provided to allow the escape of gas generated when brazing flux is heated. It also must be kept in mind that the heat of brazing causes the parts involved to expand, and if different metals are involved, different expansion rates may cause movement or slippage of the parts. When this is apt to occur, provide steps, stakes, or some holding means to keep the parts in the correct position. (See Fig. 7.4.7.)

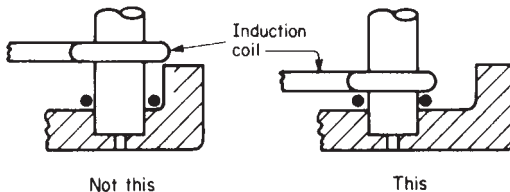


FIGURE 7.4.10 If induction heating is to be used, make sure that the design allows room for the coil.

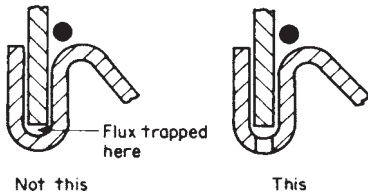


FIGURE 7.4.11 If dip brazing is used, avoid designs which entrap flux.

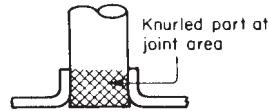


FIGURE 7.4.12 The tolerance to be applied to a dimension across a brazed joint depends on the tolerances required by the parts to be joined as well as on the variations in thickness of the film of filler metal. Knurling permits concentricity of the assembly to be maintained while still allowing room for filler metal to flow by capillary action.

If induction heating is used, the joint must be designed to allow space for proper location of the induction coil. (See Fig. 7.4.10.) Dip-brazed assemblies must be designed so that flux from the bath is not trapped in the joint. (See Fig. 7.4.11.)

Clearances for brazed metal or solder will cause a variation in the location of the parts to be joined. If critical, this variation can be controlled by knurling the parts, providing other means of minimizing the clearance before assembly, or swaging or crimping after assembly but before brazing. (See Fig. 7.4.12.)

DIMENSIONAL FACTORS

Tolerances of brazed and soldered assemblies are very largely determined by the tolerances of the component parts of the assemblies. However, it is often possible to perform finish-machining operations after brazing if some dimension must be held to closer limits than are possible in the component parts or the joined assembly. Thermal effects are paramount in causing the dimensional variations that do result from brazing (or soldering) operations. There is, of course, some across-the-joint dimensional variation that shows up as variations in filler-metal thickness in the assembly, but this is usually a result of part variation or fixturing factors rather than variations inherent in the solder or braze metal itself. Across-the-joint dimensions sometimes can be controlled by fixturing.

RECOMMENDED TOLERANCES

Across-the-Joint Dimensions

If no heat distortion is involved (with solder and low-temperature brazing alloys), the assembly tolerance should approximately equal the stack-up of tolerances of the individual parts plus an allowance for gap variations. A good average figure for this is $+0.05$ mm (0.002 in). If heat distortion is involved [likely if temperatures exceed 700°C (1300°F)], add the expected distortion variation to this total tolerance.

Concentricity across the Joint

Allow the variation permitted by the tolerances of the individual parts except when, with preapplied *paste* filler metal, it is possible to rotate one of the parts to be joined and thereby to distribute the paste uniformly and reduce eccentricity. In this case, apply one-half the tolerance that would result from the parts' spacing. The same reduction in tolerance can be made if torch brazing is used and one part can be rotated manually while the filler metal is molten.

